

United States General Accounting Office

GAO

Report to the Chairman, Subcommittee  
on Environment, Energy, and Natural  
Resources, Committee on Government  
Operations, House of Representatives

March 1994

# CHEMICAL WEAPONS DESTRUCTION

## Advantages and Disadvantages of Alternatives to Incineration



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United States  
General Accounting Office  
Washington, D.C. 20548

National Security and  
International Affairs Division

B-256519

March 18, 1994

The Honorable Mike Synar,  
Chairman, Subcommittee on Environment,  
Energy, and Natural Resources  
Committee on Government Operations  
House of Representatives

Dear Mr. Chairman:

As requested, we have reviewed selected technological disposal processes that may be alternatives to the incineration of chemical weapons. Specifically, we evaluated the development status of these alternative technologies with respect to meeting the legal deadlines for destroying the chemical weapons stockpile, the cost of the technologies, and their performance characteristics compared to incineration.

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## Results in Brief

The alternative disposal technologies identified as most likely to be feasible are in the initial stages of development and over a decade away from full-rate operations. It is unlikely that any of these technologies will reach maturity in time to destroy the entire U.S. chemical weapons stockpile by the congressionally mandated deadline of December 31, 2004.

A recent National Research Council (NRC) report, Recommendations for the Disposal of Chemical Agents and Munitions, advocates concurrent development (beginning operations before completing development, testing, and evaluation) of neutralization and one of three other combinations of alternative technologies for use in destroying bulk agent at two storage sites. The report also indicates that this approach may achieve full-rate operations by the congressional deadline. However, experience with concurrent development in the government arena shows that it carries certain inherent risks—especially when complex or novel technologies are involved—in terms of technical performance, permit delays, testing delays, and increased cost. We are concerned about counting on concurrency resulting in an alternative to the current incineration technology. In addition, the Environmental Protection Agency (EPA) has stated that any alternative technology would have to undergo the same type of rigorous analysis and evaluation that the chemical weapons incineration process has gone through—a process that has required at least 9 years.

Because these technologies are in the earliest stages of development, cost estimates are either nonexistent or unreliable. Similarly, their performance compared with incineration cannot be determined yet. If development of these technologies began this year, and concurrent development was not used, it could take until about 2007 to 2011 before they could be used to begin destroying the chemical weapons stockpile. These dates are based on NRC estimates that include such factors as research, development, design, testing, and permitting.

Each alternative technology has certain disadvantages that must be overcome. In addition, any one of these technologies would not be sufficient, by itself, to dispose of an entire chemical weapon. For example, a given alternative technology might destroy the chemical agent but not destroy or decontaminate the body of the munition. This means multiple alternative technologies would be necessary, which could result in considerable program delays and additional costs.

EPA has testified that the Army's current disposal program fully complies with or surpasses EPA requirements for environmental and public health protection. The incinerator at the Army's Johnston Atoll facility is meeting EPA incineration emissions standards. Its emissions are continuously monitored for chemical agent release, and its destruction and removal efficiency is significantly higher than that of commercial hazardous waste incinerators. While the Johnston Atoll facility has had mechanical and training problems, which have slowed its destruction rates, there have been no reported problems associated with destroying the chemical agents within EPA requirements.

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## Background

The Army is the custodian of the United States' 25,000-ton stockpile of unitary chemical weapons, currently stored at eight sites in the United States and at Johnston Atoll in the Pacific. (App. I shows the storage locations in the continental United States.) The weapons include projectiles, mines, and rockets that contain three types of lethal chemical agents: GB, VX, and H. GB and VX are nerve agents that disrupt the nervous system and usually cause death. The H series of agents, commonly called mustard, blister the skin and can lead to death with exposure to large doses. Chemical agents are also stored in bulk containers.

From 1970 through 1976, the Army destroyed chemical weapons and agents by incineration and neutralization at Rocky Mountain Arsenal,

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Colorado. However, the neutralization technology proved to have several drawbacks, and the Army began searching for an alternative technology. In 1979, the Army built a prototype high-temperature baseline incineration facility at Tooele, Utah. (See the glossary for a definition of baseline incineration.) The Army chose baseline incineration in 1981 as the best and safest method for destroying chemical weapons. In 1984, NRC endorsed this choice.

In 1985, the Army began construction of a fully integrated baseline incineration facility at Johnston Atoll. Today, the Johnston Atoll facility is close to reaching full-rate operations. A second high-temperature incineration plant at Tooele, Utah, is undergoing systemization testing, and the Army expects it to begin disposal operations by 1995. The Army plans to build seven more facilities at the other chemical weapons storage sites in the continental United States.

The fiscal year 1993 Defense Authorization Act (P.L. 102-484) requires that the Department of Defense destroy the U.S. stockpile of chemical weapons and agents by December 31, 2004. Previous legislation had established earlier deadlines. In January 1993, the United States signed the United Nations-sponsored Chemical Weapons Convention, an international treaty that is intended to prohibit the production, stockpiling, and use of chemical weapons. If the treaty is ratified by the U.S. Senate, the deadline for destroying the stockpile could be as early as 2005.<sup>1</sup> The treaty also includes a provision for a 5-year extension, which would extend the deadline to about 2010. Leaders of the Russian Federation have indicated they will ask for the extension.

Since the Army established its program in 1988, about \$1.5 billion has been expended. Currently, the total program life-cycle cost is projected to be \$8.6 billion through 2004, which is an increase of 406 percent from the original estimate. (Apps. II and III contain additional cost data.) The Army has testified that program costs could continue to rise over the life of the program for any of the following possible reasons: design changes, permit delays, more stringent regulatory requirements imposed by the states or federal government, schedule extensions, and additional costs of plant closures and dismantling.

Army studies state that the risks posed by continued chemical weapon storage, while very small, far exceed the risk of disposal. For example, a

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<sup>1</sup>The Chemical Weapons Convention enters into force 180 days after the 65th signatory country has ratified the treaty, but no earlier than January 1995. Signatory countries will have 10 years from the date the treaty enters into force to comply.

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MITRE Corporation report, entitled Assessment of the U.S. Chemical Weapons Stockpile: Integrity and Risk Analysis (July 1993), states that the condition of the stockpile can be expected to degrade with time, increasing the risks posed by continued storage. The greatest risk from the chemical weapons stockpile is to communities located near the storage sites. The number of people within about 6 miles of various chemical weapons storage sites ranges from 101 in Tooele, Utah, to 44,054 in Aberdeen, Maryland.

Public opposition to incineration has come from several citizens groups, states, and environmental organizations. They have raised concerns about incineration because of questions about adverse health effects, such as birth defects, respiratory diseases, neurological damage, and cancer. The linkage between these health problems and incineration is still being researched and debated. For example, dioxins and furans have been linked to cancer and other long-term health problems.<sup>2</sup>

As a result of growing opposition to incineration, Congress, in the fiscal year 1993 Defense Authorization Act, directed the Army to submit a report on potential technological alternatives to chemical weapons incineration. Congress also directed the Army to utilize studies by NRC in preparing the report. In June 1993, NRC published its first report, entitled Alternative Technologies for the Destruction of Chemical Agents and Munitions. A second NRC study, Recommendations for the Disposal of Chemical Agents and Munitions, was published in February 1994. The Army is scheduled to provide its required report to Congress 60 days after this second NRC report. The Army's report must include:

- an analysis of the NRC's reports and recommendations;
- a comparison of the baseline disassembly and incineration process with each alternative technology recommended by NRC in terms of safety, environmental protection, and cost effectiveness; and
- the date the alternative technology will be ready for full-rate destruction and demilitarization operations.

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<sup>2</sup>Chemical Weapons Destruction: Issues Related to Environmental Permitting and Testing Experiences (GAO/T-NSIAD-92-43, June 16, 1992).

## Alternative Technologies Are Many Years Away From Maturity

The alternative technologies we reviewed would require at least 13 years—until 2007—to proceed sequentially through all stages of development and reach maturity. For example, two technologies often mentioned as feasible alternatives to incineration—steam gasification and plasma arc pyrolysis—are at the conceptual design stage of development, according to several authoritative sources. It is estimated either of these alternatives would take about 13 to 16.5 years to reach full-rate operations capacity.

Table 1 shows how long it would take eight alternative technologies to reach maturity. The table also lists the companies developing these technologies. (See app. IV for information on the advantages and disadvantages of each technology.) Table 2 summarizes the various stages involved from development through systemization for an alternative disposal technology and the estimated time required for each stage.

**Table 1: Estimated Year for Alternative Disposal Technologies to Reach Full-Rate Operations**

<b>Technology</b>	<b>Estimated year to reach full-rate operations<sup>a</sup></b>	<b>Companies and organizations involved in development</b>
Molten salt oxidation	2007 to 2008	Rockwell International, Canoga Park, Calif.
Fluidized bed oxidation	2007 to 2008	Chemical Waste Management, Inc., Geneva, Ill.
Molten metal pyrolysis	2007 to 2008	Molten Metal Technologies, Cambridge, Mass.; Elkem Technology, Oslo, Norway
Plasma arc pyrolysis	2007 to 2011	Plasma Energy Applied Technology, Inc., Huntsville, Ala.
Steam gasification	2007 to 2011	Synthetica Technologies, Inc., Richmond, Calif.
Wet air oxidation	2007 to 2008	Zimpro Passavant Environmental Systems, Inc., Rothschild, Wisc.
Supercritical water oxidation	2007 to 2008	General Atomics, San Diego, Calif.; MODAR, Inc., Natick, Mass.; Modell Development, Inc., Framingham, Mass.
Chemical neutralization	2007 to 2008	Highly Filled Materials Institute, Stevens Institute of Technology, Hoboken, N.J.; Toxco, Inc., Claremont, Calif.; Bovar Corp. Houston, Tex.

<sup>a</sup>GAO estimates are based upon the stage of development each technology has reached, as determined by NRC. The estimates assume (1) 1994 as the starting year and (2) a sequential rather than concurrent development approach.

**Table 2: Time Estimates for Alternative Technologies to Complete Stages of Development**

<b>Stage of development</b>	<b>Estimated years required</b>
Laboratory data development	1 to 2
Conceptual design	0.5
Pilot plant	4.5 to 6
Demonstration	3
Design, construction, and systemization	5
<b>Total</b>	<b>14 to 16.5</b>

Note: The time estimates assume a sequential development approach.

Source: NRC.

NRC, in its February 1994 report, stated that the time estimates for various research and development efforts could be reduced if they were performed concurrently. For example, the full-scale demonstration plant could be built while work at the pilot plant was still under way. NRC acknowledged that there would be some financial risk in this approach, but stated that some alternatives, given sound management and sufficient funding, could be developed and demonstrated in as little as 5 to 7 years.

NRC recommended consideration of the following alternative technology combinations, all based upon neutralization at the chemical weapons storage sites at Edgewood, Maryland, and Newport, Indiana:

- neutralization followed by incineration;
- neutralization followed by wet air oxidation, followed by biological oxidation;
- neutralization followed by supercritical water oxidation; and
- neutralization followed by biological treatment.

We have some concerns about using a concurrent development approach. Specifically, a concurrent schedule may not be possible because of constraints such as (1) lengthy mandatory EPA reviews and analysis of technical performance, (2) the need to demonstrate the technology to show it meets EPA standards for protecting public health and the environment, and (3) state permitting.

Furthermore, a concurrent development approach does not seem consistent with the sequential development approach that has been used by the Army in developing the baseline incineration process for use at the Johnston Atoll and Tooele, Utah, facilities. Baseline incineration has fac

rigorous, lengthy testing and permitting to ensure technical performance and compliance with EPA requirements. EPA points out that any alternative technology would have to undergo the same type of demanding testing, analysis, and evaluation that the baseline incineration process did—which took many years. The failure of a given technology in a full-scale test is conceivable. The Office of Technology Assessment has concluded that it is also possible that alternative technologies may not prove to be any better or may even prove to be worse than incineration. Moreover, the development of multiple technologies could significantly add to the cost of the disposal program if development problems and delays were encountered.

In the past the Army has underestimated the amount of time it would take state regulatory agencies to review and approve environmental permit applications. For example, although Army schedules have generally allowed 2 years for the processing of permit applications, state officials told us that the total time required to process permits for the Anniston and Pine Bluff facilities will likely exceed 3 years.<sup>3</sup>

## Cost Estimates of Alternative Technologies Are Unavailable or Preliminary

According to industry officials, in the initial stages of research and development of a complex technology, there are too many unknown factors to be able to make reliable cost estimates. NRC conducted a nation-wide search for companies involved in developing alternative disposal technologies, but 70 percent of the companies responding to the NRC solicitation for information did not offer any cost data. The cost estimates that were furnished were characterized as very rough and could be considered only partial at that time. The following are examples of the cost data furnished:

- One company reported that its demonstration model and test program would cost an estimated \$1.8 million. A pilot plant had an estimated equipment cost of \$3 million, with an operating cost of \$7,500 per 1,000 kilograms.
- Another company stated that operations and maintenance costs ranged from \$1 to \$10 per 1,000 gallons and other capital costs were \$2.5 million to \$10 million depending upon capacity.

We attempted to obtain more detailed and complete cost estimates, but companies were reluctant to provide them. The companies told us that

<sup>3</sup>Chemical Weapons Destruction: Issues Affecting Program Cost, Schedule, and Performance (GAO/NSIAD-93-50, Jan. 21, 1993).

they could not furnish reliable cost estimates until they had researched and developed their processes through the pilot plant stage, which would be years away.

Army officials told us the federal government would most likely have to pay for the development costs of the alternative disposal technologies.

## Multiple Alternative Technologies Would Be Needed

None of the potential alternative technologies we reviewed would alone be able to render the entire weapon—chemical agent, explosive, metal parts, and dunnage—unusable and decontaminated, as required by the Chemical Weapons Convention. In contrast, baseline incineration will destroy the entire weapon by itself. (See table 3.)

**Table 3: Destruction Capabilities of Baseline Incineration and Alternative Technologies**

Technology	Can the technology destroy/decontaminate ...			
	Chemical agent?	Explosives/propellants?	Metal parts?	Dunnage?
Baseline incineration	Yes	Yes	Yes	Yes
Molten salt oxidation	Yes	Yes	No	No
Fluidized bed oxidation	Yes	Yes	No	No
Molten metal pyrolysis	Yes	Yes	Yes	No
Plasma arc pyrolysis	Yes	No	No	No
Steam gasification	Yes	No	No	No
Wet air oxidation	Yes	Yes	No	No
Supercritical water oxidation	Yes	Yes	No	No
Chemical neutralization	Yes	No	No	No

According to NRC, multiple alternative technologies would be needed to destroy the weapons. NRC provided the following example to illustrate how multiple technologies would need to be combined:

- chemical hydrolysis might be used to detoxify the chemical agent drained from the munitions;

- the product of this process might then be oxidized by supercritical water oxidation;
- the effluent of this step might require further treatment, for example, in a catalytic oxidizer, before release to the environment; and
- still other alternative technologies would be required to destroy or detoxify agent residue in the remainder of the munition, and destroy or decontaminate the explosive and dunnage.

Another possible option to destroying or decontaminating the remainder of the munition is to use incineration in place of other alternative technologies.

## Johnston Atoll Incineration Facility Meets EPA Standards

The Army has stated that while it is destroying the stockpile, its primary concern is the protection of the health and safety of the workers, the public, and the environment. After the Army conducted operational verification tests at the Johnston Atoll facility from 1990 through 1993, independent oversight contractors—for both EPA and the Army—concluded in their reports that the baseline incineration equipment generally operated safely and within environmental rules and regulations.

One problem the Johnston Atoll facility did experience was some schedule slippage because of maintenance downtime. This was due to technical and mechanical problems with various equipment and the need for more training of certain personnel.<sup>4</sup> These problems did not affect the Army's ability to destroy or decontaminate chemical weapons within EPA's standards—just the rate at which destruction occurred. (For additional information on baseline incineration, see app. V.)

EPA's Deputy Director, Office of Solid Waste, has testified before Congress that the Army's disposal program fully complies with or surpasses EPA requirements for environmental and public health protection. It is EPA's position that the Johnston Atoll liquid incinerator has the cleanest organic emissions of any incinerator in the United States. We are reviewing operations of the incineration facility at Johnston Atoll and will be reporting our findings in the future.

The liquid incinerator's extremely high temperature—above 2,550 degrees Fahrenheit—results in a destruction and removal efficiency of chemical agent that is 1,000 times higher than that of a same-sized commercial

<sup>4</sup>Chemical Weapons Destruction: Issues Affecting Cost, Schedule, and Performance (GAO/NSIAD-93-50, Jan. 21, 1993).

hazardous waste incinerator. Destruction and removal efficiency refers to the extent to which the principal organic hazardous constituent—in this case chemical agent—is destroyed. Commercial incinerators, which generally do not operate at temperatures greater than 1,800 degrees, typically achieve a destruction and removal efficiency of about 99.997 percent, whereas Johnston Atoll's liquid incinerator has achieved an efficiency of 99.9999997 percent.<sup>5</sup> In addition, according to EPA, the incineration facility is continuously monitored for chemical agent release, even when it is not running.

Recently, two alterations to the baseline incineration process have been considered—charcoal filter beds or a hold, test, and release system. In February 1994, NRC recommended the study of activated charcoal filter beds as an addition to the baseline incineration process. The Army and EPA also endorse the addition of charcoal filter beds to baseline incineration because it would further eliminate the risk of toxic air emissions, and perhaps bring about greater public confidence. However, these organizations do not consider the hold, test, and release system attractive because of its size, complexity, and cost. (See app. VI for the advantages and disadvantages of these two alterations.)

Army officials estimated that the destruction of the chemical weapon stockpile will be completed by 2003. This estimate does not reflect (1) the actual destruction rates achieved during the operational verification testing at the Johnston Atoll facility or (2) unknown problems obtaining environmental permits from the states.

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## Scope and Methodology

We conducted our work at (1) the Departments of Defense and the Army, Washington, D.C.; (2) U.S. Army Chemical Materiel Destruction Agency, Edgewood, Maryland; (3) National Research Council, Washington, D.C.; (4) Environmental Protection Agency and other federal agencies, Washington, D.C.; and (5) companies identified by NRC as being involved in the development of alternative technologies. We did not seek to identify all the companies that were involved in developing these technologies. Instead, we relied upon information companies sent to NRC and data we gathered in interviewing selected companies.

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<sup>5</sup>For example, if 1 ton of material is fed into an incinerator that achieves a destruction and removal efficiency of 99.997 percent, 0.06 pounds remain undestroyed. However, if the same amount is fed into an incinerator with a destruction and removal efficiency of 99.9999997 percent, only 0.000006 pounds remain undestroyed.

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The scope of our review included evaluation of the technology involved in the Army's baseline incineration process, but not a review of the weapons disassembly process. Also, our scope did not include mechanical changes—such as cryofracture—to the incineration process.

Cost estimate data was largely based upon information provided by 34 companies to NRC in June 1992. We also met with officials of two companies and asked for up-to-date cost estimate information. However, they were unable to provide additional cost data because they needed more time to develop their technology before they could provide reliable cost estimates. We were told by knowledgeable industry officials that reliable cost information would not be available in the early stages of research and development.

We also interviewed concerned citizens, representatives of environmental groups, and state officials. We gathered and analyzed data, including correspondence, agency documents, laws and regulations, computerized data bases, previous GAO reports, and reports by other government agencies, environmental groups, NRC, and private companies.

We performed our review from December 1992 through December 1993 in accordance with generally accepted government auditing standards. As requested, we did not obtain written agency comments on this report. However, we discussed our findings with Defense and Army officials and have included their comments where appropriate. These officials generally agreed with the information presented in this report.

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Unless you announce the contents of this report earlier, we plan no further distribution of it for 30 days from its issue date. At that time, we will send copies to the Chairmen of the Senate and House Committees on Armed Services and on Appropriations and the Senate Committee on Governmental Affairs; the Director, Office of Management and Budget; the Secretaries of Defense and the Army; and other interested parties. We will also provide copies to others upon request.

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Please contact me at (202) 512-8412 if you or your staff have any questions concerning this report. The major contributors to this report are listed in appendix VII.

Sincerely yours,

A handwritten signature in black ink, reading "Donna Heivilin". The signature is written in a cursive style with a large, prominent initial "D".

Donna M. Heivilin  
Director, Defense Management  
and NASA Issues



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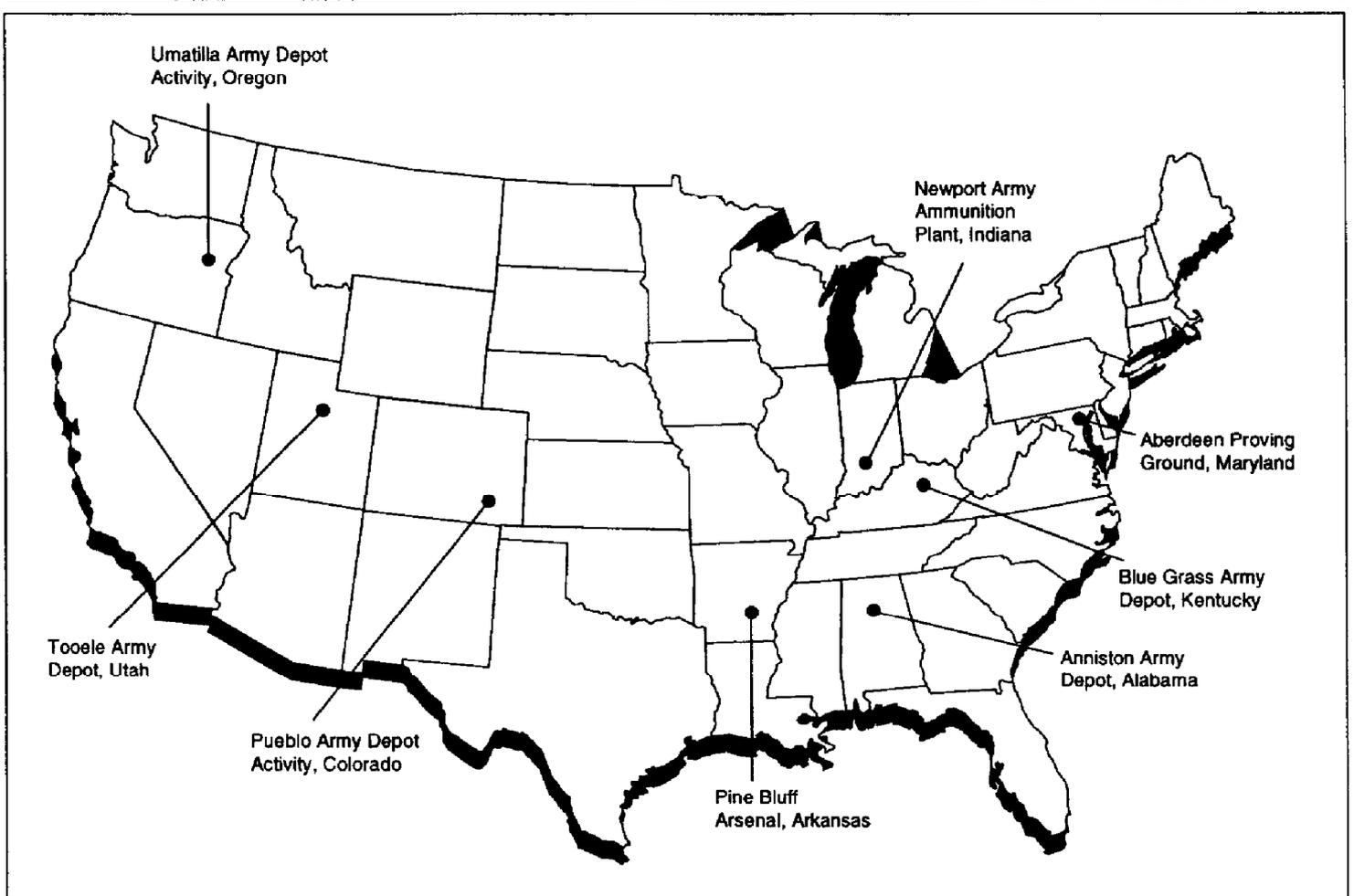
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**Abbreviations**

EPA      Environmental Protection Agency  
NRC      National Research Council

# Chemical Weapon Storage Locations in the Continental United States



# Cost Information on the Army's Incineration Program

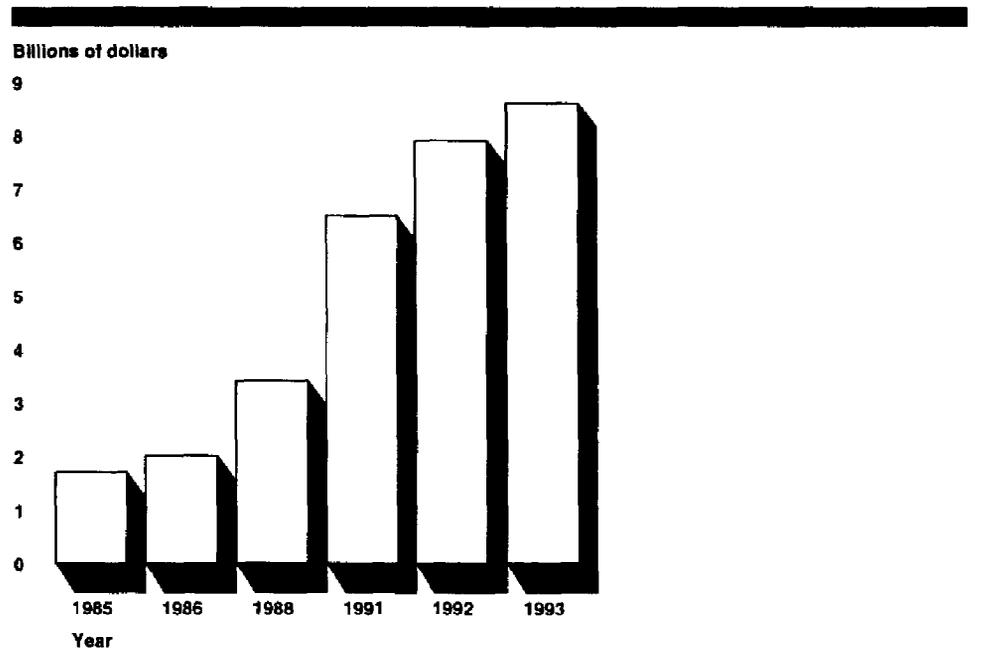
**Table II.1: Army's Estimated Life-Cycle Costs for the Chemical Stockpile Disposal Program**

Dollars in billions

Year*	Life-cycle cost estimate	Dollar increase	Percent increase	Cumulative dollar increase	Cumulative percent increase
1985	\$1.7				
1986	2.0	\$0.3	18	\$0.3	18
1988	3.4	1.4	70	1.7	100
1991	6.5	3.1	91	4.8	282
1992	7.9	1.4	22	6.2	365
1993	8.6	0.7	9	6.9	406

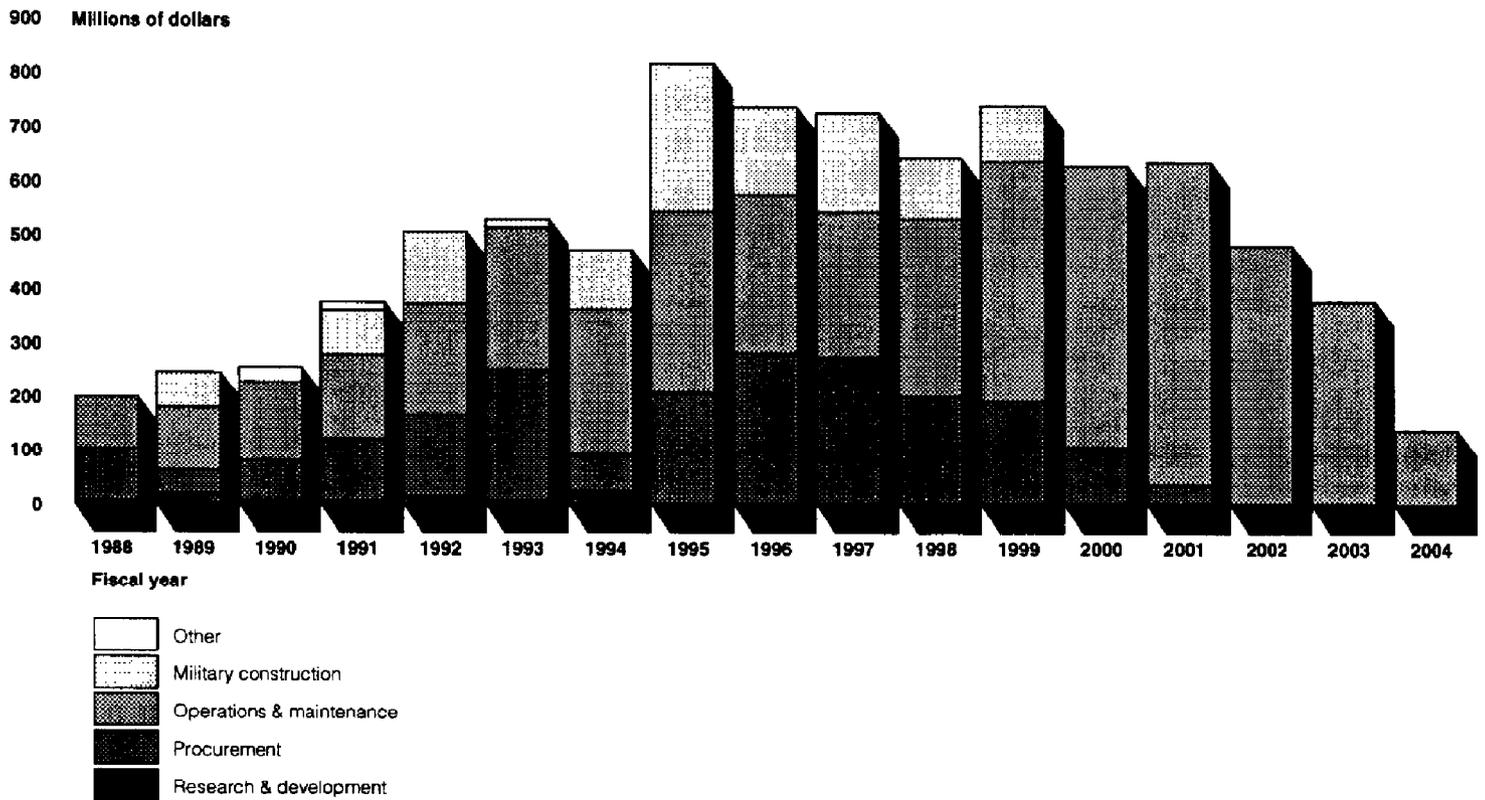
\*The Army did not calculate life-cycle cost estimates in 1987, 1989, and 1990.

**Figure II.1: Growth in the Estimated Life-Cycle Costs**



Source: GAO analysis of Army data.

# Chemical Stockpile Disposal Program Funding, 1988-2004



Note: Funding levels for fiscal years 1988 through 1993 are actual; funding levels for fiscal years 1994 through 2004 are planned.

Source: GAO analysis of Army budget data.

# Advantages and Disadvantages of Selected Alternative Technologies

To compile information on the advantages and disadvantages of alternative technologies, we interviewed various knowledgeable people and analyzed numerous sources of information. Some of the major sources were: (1) Recommendations for the Disposal of Chemical Agents and Munitions (NRC, Feb. 4, 1994); (2) Alternative Technologies for the Destruction of Chemical Agents and Munitions (NRC, June 10, 1993); (3) Disposal of Chemical Weapons: Alternative Technologies (Office of Technology Assessment, July 1992); (4) Alternative Technologies for the Detoxification of Chemical Weapons: An Information Document (Greenpeace International, May 24, 1991); (5) briefings, reports, and information from companies identified by NRC as being involved in the development of alternative technologies; (6) data and information we gathered from companies involved in the development of alternative technologies; (7) interviews, reports, and testimony by the Army; and (8) our previous reports. The advantages and disadvantages listed in this appendix are not intended to be all-inclusive.

Description of technology	Advantages	Disadvantages
<p><b>Molten salt oxidation:</b> Combines chemical and thermal treatment. Wastes and oxygen are fed into a bath of molten caustic salt—usually sodium carbonate or a mixture of sodium and potassium carbonate. The wastes are oxidized, typically producing emissions of carbon dioxide, water, nitrogen, and oxygen; ash and soot are retained in the melt. Salt can later be removed for disposal or for processing and recycling.</p>	<ul style="list-style-type: none"> <li>— A private company, using Army personnel, has considerable laboratory experience and expertise, testing with small amounts of mustard agent and dunnage since 1950.</li> <li>— No mustard was detected in gas emissions, and destruction and removal efficiency was very high.</li> </ul>	<ul style="list-style-type: none"> <li>— The possibility of superheated vapor explosions is a safety hazard.</li> <li>— During tests on mustard agent, small amounts of nitric oxides, organically bound chlorine, and traces of hydrocarbons were found in gas emissions, which could adversely impact the environment.</li> <li>— The salts removed from the molten salt bath will contain all the normal salts produced by incineration (sodium fluoride, chloride, sulfate, etc.). The total volume will exceed that of incineration because of unreacted material from the salt bath. These salts are all soluble and will have to be treated as toxic waste in a landfill.</li> <li>— The long-term mechanical operability of the molten salt oxidation reactor has not been demonstrated, and problems may occur.</li> </ul>

(continued)

**Appendix IV  
Advantages and Disadvantages of Selected  
Alternative Technologies**

Description of technology	Advantages	Disadvantages
<b>Fluidized bed combustion:</b> Uses fluidized, granular solid as heat transfer medium. For chemical agent destruction, solid of choice would be aluminum oxide or calcium oxide. The material is kept suspended by gas flow, which is primarily air.	<ul style="list-style-type: none"> <li>— Proven technology in civilian hazardous waste incinerators.</li> <li>— Allows rapid start-up and shutdown of feed stream, increasing safety.</li> <li>— Use of slurry reduces concern for explosion when destroying propellants and explosives.</li> </ul>	<ul style="list-style-type: none"> <li>— Difficult to achieve desired destruction and removal efficiency for chemical agents.</li> </ul>
<b>Molten metal pyrolysis:</b> Involves use of metals, such as copper, iron, or cobalt, at 3,000 degrees Fahrenheit, to decompose organic compounds like chemical agent.	<ul style="list-style-type: none"> <li>— Molten metal furnace could combine functions of three of the incinerators used in the current technology.</li> </ul>	<ul style="list-style-type: none"> <li>— Gases from the furnace would likely be very dirty, containing soot from the metal pyrolysis and possibly some slag particulate matter. Separate purifier unit would be needed to clean gas before it is released.</li> <li>— Gases from the furnace are combustible organic materials which must be burned in a separate afterburner or furnace.</li> </ul>
<b>Plasma arc pyrolysis:</b> Involves passing an electric current through a low-pressure airstream to split chemical agent into its atomic elements in a thermal plasma field at a very high temperature, e.g. 10,000 degrees Fahrenheit.	<ul style="list-style-type: none"> <li>— Short start-up and shutdown times, increasing safety.</li> </ul>	<ul style="list-style-type: none"> <li>— The arc furnaces produce a combustible gas that would require a secondary burner and gas clean-up system just as with normal incineration.</li> <li>— Costly labor-intensive operations.</li> </ul>
<b>Steam gasification:</b> Organic materials are treated with super-heated steam under reducing conditions to produce simple organic molecules. Also known as reformation.	<ul style="list-style-type: none"> <li>— May be operated as a closed-loop system; waste streams are stored until chemical analysis establishes their suitability for disposal.</li> </ul>	<ul style="list-style-type: none"> <li>— Another technology would be required because the products of the process would require further oxidation.</li> <li>— Possible air leakage could lead to fires.</li> <li>— Chemical agents would be particularly difficult to handle because of their large content of elements such as fluorine and phosphorous (in GB), nitrogen and phosphorous (in VX), and chlorine (in mustard). A large development effort is probable.</li> <li>— Requires significant costly energy usage.</li> <li>— Suitable cooling should be used to safely remove heat of reaction.</li> </ul>

(continued)

**Appendix IV  
Advantages and Disadvantages of Selected  
Alternative Technologies**

<b>Description of technology</b>	<b>Advantages</b>	<b>Disadvantages</b>
<p><b>Wet air oxidation:</b> Based on principle that organic compounds can be oxidized slowly at temperatures that are low compared with normal combustion temperatures (e.g. 572 degrees Fahrenheit versus 3,632 degrees Fahrenheit). The oxidation is carried out at high pressure, e.g. 1,000 per square inch, in the presence of water.</p>	<ul style="list-style-type: none"> <li>— Approximately 200 municipal and hazardous waste plants use this technology worldwide.</li> <li>— An effective way of oxidizing organic matter in dilute aqueous solution. Thus, it could be particularly useful for the case where agent is first chemically detoxified, resulting in an aqueous solution requiring further oxidation.</li> <li>— It has been tested with a number of insecticides, and fungicides having chemical compositions that resemble those of chemical weapons.</li> </ul>	<ul style="list-style-type: none"> <li>— High operating pressure could result in potentially dangerous chemical agent leaks.</li> <li>— A major containment structure would be needed, adding greatly to capital costs and construction times.</li> <li>— The liquid product will contain appreciable concentrations of organic compounds such as acetic acid; while they are non-toxic, they will require further treatment before release of the water to the environment.</li> <li>— Gas emissions contain appreciable concentrations of volatile organic compounds and will require additional treatment before release to the atmosphere.</li> <li>— Corrosion is a concern, possibly affecting structural integrity of the facility.</li> </ul>
<p><b>Supercritical water oxidation:</b> Involves mixing chemical agents with water that has been pressurized and heated to a point at which organic compounds become soluble. (Above 705 degrees Fahrenheit, and a pressure above 221 atmospheres, or 3,205 pounds per square inch.) Solution is oxidized at an elevated temperature, producing carbon dioxide and inorganic acids and salts.</p>	<ul style="list-style-type: none"> <li>— The aim of supercritical water oxidation is to have complete oxidation, with no products of incomplete combustion remain in solution.</li> <li>— Liquid effluent may be collected and analyzed, then recycled if found harmful to the environment.</li> <li>— A private company has experience testing the technology with dilute solutions of GB and VX nerve agents, and it achieved a very high destruction and removal efficiency using a laboratory-sized reactor.</li> <li>— It would be particularly useful with a feed consisting of products from a previous detoxification step; the detoxified material would be in dilute aqueous solution, the form required for supercritical water oxidation.</li> </ul>	<ul style="list-style-type: none"> <li>— High operating pressure could result in potentially dangerous leaks.</li> <li>— Because feedstock may only contain a maximum of 20 percent agent, the amount of liquid wastes is greatly increased.</li> <li>— A major containment structure would be needed, adding greatly to capital costs and construction times.</li> <li>— Problems with corrosion of parts and salt formation inside reactor chamber may adversely affect facility operations.</li> </ul>

(continued)

**Appendix IV  
Advantages and Disadvantages of Selected  
Alternative Technologies**

<b>Description of technology</b>	<b>Advantages</b>	<b>Disadvantages</b>
<p><b>Chemical neutralization:</b> Involves mixing chemical agents with other substances to form less toxic compounds. An example of this process is hydrolysis—the breakdown of a chemical agent by water.</p>	<ul style="list-style-type: none"> <li>— Army has experience in chemically neutralizing GB nerve agent. The Canadians have recent experience in neutralizing small amounts of nerve agents GA, GB, and VX, and the chemical agent lewisite.</li> <li>— Because no appreciable exhaust gases are released, there is no need for a complex pollution abatement system.</li> <li>— Would produce smaller amounts of gaseous effluents.</li> <li>— Low operating pressure reduces risk of potentially dangerous leakage.</li> <li>— Avoids formation of dioxins, furans, and other undesirable products from chlorinated compounds because of low operating temperature.</li> </ul>	<ul style="list-style-type: none"> <li>— The products of the process are not suitable for release to the environment, they must be oxidized to final stable materials that are suitable for release.</li> <li>— By-products of the process are extremely variable, which can cause problematic emissions.</li> <li>— Process is slow compared to incineration.</li> <li>— Mustard agent and VX are hard to neutralize; other technologies may be necessary for disposal.</li> <li>— Because feedstock may only contain a maximum of 20 percent agent (for VX and mustard), the amount of liquid wastes is greatly increased.</li> <li>— The time required to develop a neutralization-based process for use at any specific site may be 3 to 5 years longer than for baseline incineration.</li> </ul>

# Advantages and Disadvantages of Baseline Incineration

Description of technology	Advantages	Disadvantages
<p><b>Baseline incineration:</b> An engineering process that employs thermal decomposition via thermal oxidation at high temperature to destroy the organic portion of the waste and reduce volume.</p> <p>Chemical weapons are drained of chemical agent and disassembled, then component parts are sent to one of four incinerators: (1) agent is pumped from holding tanks to a liquid incinerator, (2) casings are decontaminated in a metal parts furnace, (3) explosives and propellants are burned in a deactivation furnace, and (4) packing materials are burned in a dunnage incinerator. Each furnace possesses its own pollution abatement system, all of which lead to a common exhaust stack.</p>	<ul style="list-style-type: none"> <li>— Can destroy or decontaminate the entire munition, so no other technologies are needed.</li> <li>— Is the only fully developed process to dispose of chemical weapons.</li> <li>— Substantial design and operational experience exists.</li> <li>— Has been used by the United States, United Kingdom, Canada, and Russia as a means of disposing of chemical weapons.</li> <li>— Has been thoroughly tested with all chemical agents.</li> <li>— Thus far has fully complied with or surpassed EPA requirements for environmental and public health protection.</li> <li>— Capable of a high degree of destruction— has demonstrated destruction and removal efficiency of 99.999997 percent with nerve agent.</li> <li>— Can decontaminate metal parts to a level where they can be sold to the public as scrap.</li> <li>— Process is irreversible, thus satisfying terms of the Chemical Weapons Convention.</li> </ul>	<ul style="list-style-type: none"> <li>— Many health effects are still unknown. Over 17,000 papers on dioxins have been published without settling controversies about human health effects.</li> <li>— Complex pollution abatement systems needed to remove particulates and acid gases.</li> <li>— Combustion problems could increase emission of products of incomplete combustion.</li> <li>— Many citizens and environmental groups believe there are risks to the public and the environment.</li> <li>— Visible exhaust plume from stack could be misinterpreted by public as hazardous pollutants.</li> </ul>

# Advantages and Disadvantages of Possible Alterations to Baseline Incineration

Description of process	Advantages	Disadvantages
<p><b>Charcoal filter beds:</b> A bank of several activated charcoal filters would be added to the end of the baseline incineration process. The filters would catch any particulates, products of incomplete combustion, or chemical agent that might make it through the pollution abatement system.</p>	<ul style="list-style-type: none"> <li>— The addition of filters could instill a greater level of public confidence, as it would virtually eliminate the risk of toxic air emissions.</li> <li>— Carbon filtration has been used successfully in both Germany and Italy.</li> <li>— A similar filter system is already used on the ventilation system at the Army's Johnston Atoll facility and would be used at all subsequent facilities in the continental United States</li> <li>— Such a system is commercially available and would require minimal testing.</li> <li>— Gas cooling and condensation would eliminate visible exhaust plume.</li> <li>— Should greatly reduce false alarms from exhaust monitors.</li> </ul>	<ul style="list-style-type: none"> <li>— About \$200 to \$300 million would be added to the program's estimated life-cycle cost.</li> <li>— Incinerator exhaust gases must be cooled and dehumidified to a temperature and humidity similar to building ventilation conditions to ensure effective filtration.</li> <li>— Cooled exhaust gases will generate additional wastewater to be managed.</li> <li>— Care must be taken to avoid fires; temperatures must be carefully monitored and controlled.</li> <li>— Poor removal efficiency due to leakage around or through the carbon beds.</li> <li>— Loss of adsorption capacity if water contacts the charcoal.</li> </ul>
<p><b>Hold, test, and release:</b> Involves collecting incinerator emissions in several large collapsible holding tanks. Once filled, a tank's contents would be analyzed for toxic substances. If safe, the tank would be emptied to the atmosphere. If not, then the tank's contents would be recycled through the afterburner.</p>	<ul style="list-style-type: none"> <li>— The addition of a hold, test, and release system could instill a greater level of public confidence, as it would virtually eliminate the risk of toxic air emissions.</li> <li>— Holding tanks are commercially available.</li> <li>— Gas cooling and condensation would eliminate visible exhaust plume.</li> </ul>	<ul style="list-style-type: none"> <li>— Cost for capability to hold emissions for 8 hours is estimated at \$250 million per site, adding about \$2.25 billion to the program's estimated life-cycle cost. To more thoroughly analyze emissions, they must be held for 48 to 72 hours, resulting in at least a six-fold cost increase.</li> <li>— Incinerators would require substantial engineering redesign for treatment of contaminated emissions.</li> <li>— This process is not being used on any incinerator in the world.</li> <li>— Liquid would condense within the tank once the emissions cool, which also must be analyzed and managed in a wastewater treatment system.</li> <li>— If emissions are found to be contaminated, then both the tank and its contents must be decontaminated.</li> </ul>

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# Glossary

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Afterburner	A device for burning unburned or partially burned compounds in exhaust.
Aqueous	Made from, with, or by water.
Baseline Incineration	A high-temperature incineration process involving a disassembly procedure that breaks down munitions into their component part. Once disassembled, the chemical agent and the munition components are burned separately in four furnaces.
Combustion	An act or instance of burning; a chemical process (as an oxidation) accompanied by the evolution of heat.
Convention	A treaty.
Cryofracture	An experimental munitions disassembly technique through which a chemical munition is frozen in liquid nitrogen and crushed to pieces in a hydraulic press; the pieces are then incinerated. Cryofracture is only visualized as a munitions disassembly process and is not considered an alternative to incineration.
Decontamination	The process of decreasing the amount of chemical agent on any person, object, or area by absorbing, neutralizing, destroying, ventilating, or removing the agent.
Destruction and Removal Efficiency	The extent to which a chemical agent or other hazardous material is destroyed, expressed as a percentage.
Detoxify	To remove a poison or toxin, or the effect of such.
Dioxins (Dibenzo-P-Dioxins)	Organic compounds that are sometimes created as a result of incomplete combustion or the recombination of exhaust products from the burning of mixtures containing certain chlorinated organic compounds.
Dunnage	Shipping and packaging material for munitions.
Effluent	Waste material discharged into the environment.

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Glossary

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Fluidized	Suspended in a rapidly moving stream of gas or vapor to induce flowing motion of the whole for enhancing a chemical or physical reaction.
Furans (Dibenzofurans)	Organic compounds that are sometimes created as a result of incomplete combustion or the recombination of exhaust products from the burning of mixtures containing certain chlorinated organic compounds.
Hydrolysis	A name given to a group of chemical reactions where two or more chemicals, in water, react together to form a salt as one of the products; a type of chemical neutralization.
Incineration	Another word for combustion.
Neutralization	The act of altering the chemical, physical, and toxicological properties to render the chemical agent ineffective for use as intended.
Oxidation	The process of combining with oxygen; to dehydrogenate, especially by the action of oxygen. Combustion is the most common oxidation process.
Particulate	A substance composed of or relating to minute separate particles.
Plasma	A substance that exhibits some properties of a gas but differs from a gas in being a good conductor of electricity.
Products of Incomplete Combustion	Compounds that result from all types of combustion where there is incomplete mixing, insufficient time in the incinerator, or insufficiently high temperature. These compounds are generated in very small amounts.
Pyrolysis	A chemical change brought about by the action of heat in the absence of oxygen.
Reducing	To deoxidize; to combine with or subject to the action of hydrogen.

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Glossary

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Salts	Solid compounds produced during a chemical neutralization reaction; any of numerous compounds that result from replacement of part or all of the acid hydrogen of an acid by a metal or a group acting like a metal.
Slurry	A watery mixture of insoluble matter.
Soluble	Capable of being dissolved.
Systemization	The period when the individual systems of a disposal facility are tested as an integrated system and training and simulant munitions are processed through the system. It also includes the comprehensive certification of all workers and pre-operation checks by government officials.
Unitary	A munition containing only one chemical, that being a lethal agent.
Volatile	Readily vaporizable at a relatively low temperature.

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